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Remote Sensing of Multilevel Clouds During FIRE IFO II

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1. Introduction

An unresolved difficulty in the remote sensing of clouds concerns the inability of the cloud retrieval algorithms to adequately recognize and analyze scenes containing overlapping cloud layers. Most cloud retrieval schemes, such as that used by the International Satellite Cloud Climatology Project (ISCCP) (Schiffer and Rossow, 1983), assume that each picture element (pixel) contains a single cloud layer. The current study begins to address the complexities of multilayered cloud property retrieval through the application of a modified multispectral, multiresolution (MSMR) method , first detailed in Baum et al. (1992), which merges 1.1-km (at nadir) spectral data from the Advanced Very High Resolution Radiometer (AVHRR) with 17.4-km (at nadir) High Resolution Infrared Radiometer Sounder (HIRS/2, henceforth HIRS). Both instruments are flown aboard the National Oceanic and Atmospheric Administration (NOAA) polar-orbiting platforms. An ideal case study for this investigation is provided by the NOAA-11 overpass at 20:48 UTC on November 28, 1991. At this time, a large-scale cirrostratus veil overlaid a low-level stratus deck over much of the IFO region. There were both surface lidar and radar observations of the clouds as well as University of North Dakota (UND) Citation aircraft measurements. The presence of overlapping cloud layers within a HIRS FOV is determined from colocated AVHRR spectral data through the use of a fuzzy logic expert system (Tovinkere et al., 1993). Conventional algorithms such as spatial coherence (Coakley, 1983) and CO_2 slicing (McCleese and Wilson, 1976; Smith and Platt, 1978) are used to retrieve cloud pressure and height for each identified cloud layer. The results from the satellite cloud retrieval analysis are compared to results from both surface- and aircraft-based measurements.

2. Data

Further details on the AVHRR and HIRS instruments, spectral channels, and sampling may be found in Kidwell (1991). The raw counts for the AVHRR infrared channels (10.8- and 12-mm) are converted to radiances using the nominal calibration (Kidwell, 1991) and to brightness temperature using the nonlinearity corrections of Weinreb et al. (1990). The MSMR cloud retrieval method uses temperature and relative humidity data collected during the FIRE IFO II by NWS (National Weather Service) and CLASS (Cross Chain Loran Atmospheric Sounding System) sondes and the European Center for Medium Range Weather Forecasting (ECMWF). Cloud heights and cloud bases are compared to a variety of surface observations recorded at Parsons and Coffeyville in addition to cloud heights recorded by the UND Citation. Coffeyville surface observations include the NOAA 8.6-mm radar and NOAA lidar, and the Pennsylvania State University (PSU) 3-mm radar. The Langley Research Center (LaRC) lidar took observations at Parsons.

3. Methodology

The MSMR method incorporates techniques such as CO_2 slicing (e.g. McCleese and Wilson, 1976; Smith and Platt, 1978) to estimate cloud height, threshold methods to calculate fractional coverage, and radiative transfer theory to infer bulk optical properties. Details of the MSMR scheme may be found in

Baum et al. (1992). The MSMR cloud pressure retrieval schematic shown in Figure 1 has since been modified to include the spatial coherence technique (Coakley, 1983), a scheme for analyzing temperature profile data to infer tropopause height, and a surface elevation map. In addition, the MSMR scheme uses a hybrid relative humidity profile that incorporates both the relative humidity of water and ice (Starr and Wylie, 1990). To determine whether more than one cloud-layer is present, we employ an artificial intelligence method to automatically classify a subset of AVHRR spectral data colocated with a HIRS field of view (FOV). A variety of classificiation techniques have been discussed in the literature over the past 30 years, but only until recently have these techniques been applied to satellite data (e.g. Garand, 1988; Ebert, 1987; Welch et. al., 1992). However, one drawback to many of these techniques is that a given data sample may contain mixed classes of cloud, such as cirrus over stratus. In such a case, a classifier using a clustering technique is able to provide information on only the most prevalent cloud class. Fuzzy logic classification has the ability to assign multiple classes to a given data sample. For example, a given array of AVHRR data may be assigned membership values for both cirrus and stratus, or cirrus, land, and water. A fuzzy logic expert system (Tovinkere et al., 1993) is prepared for use in the MSMR methodology in order to attempt classification of subgrid cloud layering through analysis of the AVHRR data collocated with each HIRS FOV. The fuzzy logic approach uses both textural and spectral features calculated from a 32x32 pixel array of AVHRR data collocated with each HIRS FOV to determine whether the following five classes are present, either singly or in combination: (1) land; (2) water; (3) unbroken stratiform cloud; (4) broken stratiform cloud; and (5) cirroform cloud. These classes are broad in scope and may contain a number of representative subclasses. For instance, land covers all surface not covered by water, unbroken stratiform includes both stratus and altostratus cloud types, broken stratiform includes both stratus and altostratus cloud types in which some amount of surface is uncovered by cloud in the data array, and cirroform includes cirrostratus, cirrus uncinus, and other cirrus types. If the classification shows that any low cloud is present, the assumption is made that the HIRS pixel has a lower cloud layer effective cloud amount of 1 (εA_c=1, where ε is emittance and A_c is cloud fraction). The HIRS radiometric data are then reanalyzed with the surface defined to be the lower cloud top pressure instead of the ground. When a low cloud is used as the lower surface instead of the ground, the end result is to increase the cloud height from the value obtained using a single cloud layer assumption. When the cirrus becomes very thin (i.e, $\varepsilon < 0.2$), the cloud signal tends to become small in the HIRS 15-µm channels with the result that the retrieved cloud pressures may be dependent on the choice of channels. When cloud pressures vary widely with channel choice, the most likely cloud pressure is assumbed to be the one that corresponds with a maximum in the relative humidity of ice .

4. Results

Results from the November 28, 1991 NOAA-11 overpass at approximately 20:48 UTC are shown in Figure 2 for the MSMR-derived cloud heights. In Figure 2, the ellipses refer to HIRS pixels (not drawn to actual size) and contain the MSMR-derived cloud height in kilometer (km). There is some uncertainty for very thin cirrus as to whether the cirrus cloud heights are actually cloud top or cloud center. The lower layer cloud top height is determined from spatial coherence analysis to be 1.9 km. The classification system determined that both cirroform and broken stratiform cloud were present in each of the HIRS pixels noted in the figure. The Coffeyville and Parson sites are denoted by a solid dot. The hatched area refers to the flight region of the Citation. The small letters in parentheses below the surface site name are used as a reference to results shown in Table 1, where cloud height results are shown from the UND Citation aircraft and the surface lidars and radars. For the upper cloud layer, the cloud base to cloud top range is given. Analysis of CLASS sonde data showed two maxima in the vertical relative humidity profile, and the height in km of each peak is also provided in the table. The MSMR results agree well with both surface and aircraft cloud layer height observations, and are encouraging given the scene complexity.

Table 1: Surface and aircraft cloud height observations recorded during the November 28, 1991 NOAA-11 overpass at 20:48 UTC, where Z_{LC} refers to the lower clou-top height and Z_{UC} refers to upper cloud height (both cloud base and cloud top given where possible).

	INSTRUMENT	LOCATION	Z_{LC} (km) top	Z_{UC} (km) base-top
a	NOAA CO_2 LIDAR	Coffeyville	---	8.2-9 10.1-10.8
b	NOAA K-BAND RADAR	Coffeyville	1.8	8.1-9.2
c	PSU RADAR	Coffeyville	1.8	8-10
d	CLASS SONDE (RH/RHI)	Coffeyville	2.0	10
e	LaRC LIDAR	Parsons	---	8-11.3 (perhaps two layers)
f	UND Citation	See flight track (Figure 2)	1.8	8.3-11.2

5. References

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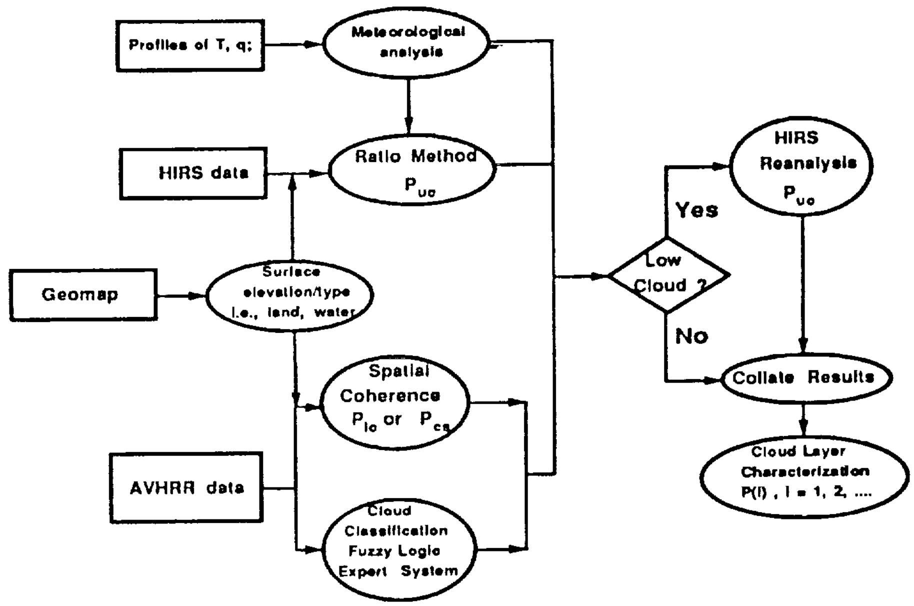

Figure 1. Schematic for merged AVHRR/HIRS data processing scheme. The subscripts lc, uc, and cs refer to lower-level cloud, upper-level cloud, and clear sky, respectively.

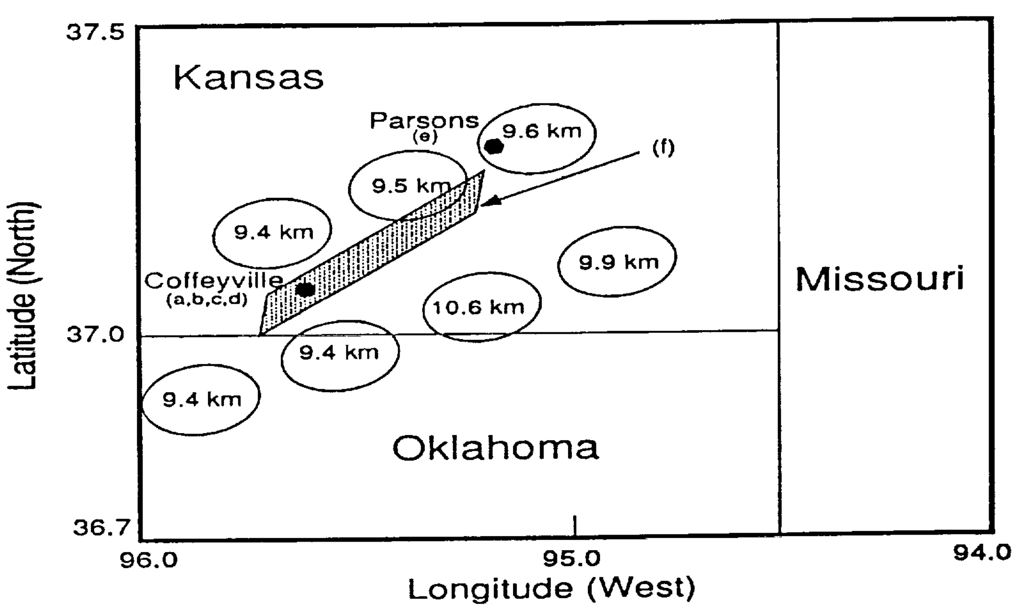

Figure 2. MSMR upper cloud height results for HIRS fields of view on November 28, 1991 at 20:48 UTC during the FIRE IFO II. The solid dots refer to locations of Coffeyville and Parsons. The cross-hatched area shows UND Citation flight track region. The small letters in parentheses under city names refer to corroborative cloud height measurements detailed in Table 2.